BIG CREEK HYDROELECTRIC SYSTEM,
FLORENCE LAKE DAM
Sierra National Forest
Big Creek vicinity
Fresno County
California

HAER CA-167-L

PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

FIELD RECORDS

HISTORIC AMERICAN ENGINEERING RECORD
National Park Service
U.S. Department of the Interior
1849 C Street NW
Washington, D.C. 20240

HISTORIC AMERICAN ENGINEERING RECORD

BIG CREEK HYDROELECTRIC SYSTEM, FLORENCE LAKE DAM

HAER CA-167-L

Location: Sierra National Forest, Big Creek Vicinity, Fresno County, CA Centerpoint of spillway at latitude 37.274, longitude -118.9684 (location data derived from Google Earth).

Present Owner: Southern California Edison Company

Present Use: The Florence Lake Dam is a multiple-arch dam on the South Fork of the San Joaquin River with a capacity of 64,000 acre-feet. It supplies water for hydroelectric generation downstream via the Ward Tunnel.

Significance: Built in 1925-1926, Florence Lake Dam is one of three major storage dams built during the 'great expansion' of Southern California Edison's Big Creek hydroelectric project. 3,156' long, Florence Lake Dam was the world's largest multiple arch dam at the time of its construction. The Big Creek system was the premiere example of integrated water storage and hydroelectric generation in the American West during the period 1911-1929. Big Creek set records in hydroelectric generation, dam construction, and tunnel excavation in rugged terrain with harsh climactic conditions. It also pioneered high-voltage transmission, allowing power to be generated in remote locations for distant markets. The Big Creek system is also significant in the history of the Los Angeles region. Conceived as a means of powering both residential development and electric railways, power from Southern California Edison's Big Creek plants was instrumental in the rise of suburban development in the region. The system is closely associated with railroad, energy, and development magnate Henry Huntington; with Edison executives and power pioneers A.C. Balch, William Kerckhoff, and George C. Ward; visionary California hydroelectric engineer John Eastwood; and Big Creek Resident Engineer David Redinger.

Historian(s): Daniel David Shoup, PhD
Archaeological/Historical Consultants
Oakland, California
November, 2012

Project Information:

Research for this report was sponsored by Southern California Edison Corporation (SCE) as part of the HAER documentation of the Big Creek hydroelectric system. Daniel David Shoup of Archaeological/Historical Consultants (Oakland, California) wrote the historical narrative. Laurence Shoup and Suzanne Baker of Archaeological/Historical Consultants conducted the historical

research between June and October 2012. HAER photography was produced by David De Vries and Marissa Rocke of Mesa Technical (Berkeley, California) in July 2012. Administrative and research support was provided by Don Dukleth of Southern California Edison, Northern Hydro Division (Big Creek, California), and Audry Williams of Southern California Edison, Corporate Environment Services Division (Monrovia, California).

This report is one of a series of HAER reports on the Big Creek hydroelectric system, which to date include:

- Powerhouse 8, Operator Cottage (HAER CA-167-A)
- Powerhouse 3 penstock standpipes (HAER CA-167-B)
- Big Creek Town, Operator House (HAER CA-167-C)
- Big Creek Town, Operator House Garage (HAER CA-167-D)
- Big Creek Powerhouse 1 (HAER CA-167-E)
- Big Creek Powerhouse 2/2A (HAER CA-167-F)
- Big Creek Powerhouse 8 (HAER CA-167-G)
- Big Creek Powerhouse 3 (HAER CA-167-H)
- Cottage 115 (HAER CA-167-I)
- Cottage 112 (HAER CA-167-J)
- Cottage 113 (HAER CA-167-K)
- Bear Creek Diversion Dam (HAER CA-167-M)

For more information on the history of the Big Creek system, see the bibliography to this and other reports in the series.

Historic photographs of the dam, intake, and construction camp are available in the Field Notes appendix to this HAER and online via the Huntington Library (San Marino, CA) website: http://hdl.huntington.org/

Historical Information

Description

Florence Lake Dam is a reinforced concrete multiple-arch dam on the South Fork San Joaquin River. The dam is 3,156' long and 149' high at its maximum point, with its crest at 7239' elevation. Arranged in five tangent sections, it is made up of 58 arches 50 feet wide, three buttresses at the junctions between tangents, and a spillway. Two sluice gates and a Stoney gate, located at the base of the dam, can be used to control reservoir levels.[1] The dam creates a reservoir with a capacity of 64,406 acre-feet. An intake tunnel under the surface of the reservoir supplies water into the Ward Tunnel for use in the Big Creek hydroelectric plants.

The Florence Lake Dam was built as part of the 'great expansion' of the Big Creek system between 1920 and 1929. Road construction to the site was begun in 1920, and the final dam site was selected in 1923. Concrete pouring took place between March 4 and October 30, 1925, and was completed between April 29 and August 15, 1926. Backfill, grouting, and the installation of handrails and gate mechanisms was completed by November 15, 1926. Because of the early completion of the Ward Tunnel, the Florence Lake intake portal began supplying water to Huntington Lake in April, 1925.

Engineering

The dam was designed by Mr. Pierce and Mr. Heywood of SCE's Los Angeles headquarters, supervised by Harry Dennis, SCE Construction Engineer, with the assistance of Harold L. Doolittle, SCE Chief Designing Engineer. Arthur Blight was Assistant Manager of Construction for SCE during the period, while David Redinger was in charge of local management of the Big Creek project as Resident Engineer.[2] E.C. Panton, assisted by T.A. Smith, Anton Wellman, and O.N. Kunberg supervised the concrete work.[3] The dam was inspired by the work of John S. Eastwood, who originally proposed the dam site in 1903-1904 and was the inventor of the reinforced concrete multiple-arch dam.[4]

Builders and Suppliers

Over 1,500 workers from the SCE Construction Department participated in the construction of the dam. Construction at Big Creek was characterized by extensive and

---

[1] The term 'Low Level Outlet Valve' (LLOV) has replaced 'sluice gate' in the industry. This report follows the historical sources on the dam's construction and retains the term 'sluice gate'. Readers should, however, be aware of the new terminology in mind when examining more recent sources on dam construction.
[2] Redinger, *Story of Big Creek,* 137-138; *Western Construction News.* "Big Creek-San Joaquin Hydro-Electric Project of the Southern California Edison Company," 32.
[3] Redinger, *Story of Big Creek,* 135.
[4] Whitney, "John Eastwood: Unsung Genius of the Drawing Board."

innovative recycling of materials: concrete aggregate was produced from tunnel waste and sawmills were established on site to provide lumber for concrete forms. The Big Creek workshops also used surplus rails and other scrap steel to produce dam elements such as trash racks.

Specialized iron and steel work, such as castings, gates, piping, cylinders, and meters, however, were purchased from outside suppliers. Llewellyn Iron works, Western Pipe and Steel, Baker Iron Works, and Lacy Manufacturing Company, all of Los Angeles, were the most prominent suppliers. Other materials were purchased from Joshua Hendy Iron Works of Sunnyvale, CA and Builder's Iron Works of Providence, RI.

Construction Narrative

Florence Lake Dam was constructed as part of the 'great expansion' of the Big Creek Hydroelectric Project from 1920 to 1929. Besides the addition of new powerhouses and turbines, the expansion required the addition of substantial new water storage.

As Shoup notes,

> The key problem facing Edison during the 1920s was how to get additional water into the Big Creek System. Although located in the high Sierra, the Big Creek area lay in the southern part of that mountain chain where rainfall–and therefore available water–was less abundant than farther north. In order to fully utilize the existing powerhouses, more water was needed than could be provided by Huntington Lake.
>
> For a solution, Edison turned to John Eastwood's original plans. As early as 1902, Eastwood had considered the viability of using waters of the southern fork of the San Joaquin River, which was separated from the BC Basin by the Kaiser Pass. His 1902 survey included measurements for a tunnel through the pass to bring water from the South Fork into BC.[5]

Florence Lake was the first water storage project of the great expansion and "in many ways constituted the centerpiece of the entire Big Creek complex."[6] Water storage on the South Fork, however, was only useful if there was a way to bring water from one watershed to another. SCE thus proposed a hard rock tunnel that would bring water from Florence Lake to Huntington Lake, where it could be distributed to the Big Creek powerhouses. Both projects were monumental engineering feats: the Florence Lake Dam was the world's longest multiple-arch dam at 3,156' long, while the Florence Lake Tunnel (renamed the Ward Tunnel in 1936 after SCE President George C. Ward) at 13 miles long was one of the world's longest hard rock tunnels.[7]

---

[5] Shoup, *The Hardest Working Water in the World,* 125.
[6] Ibid.
[7] Ibid., 115; Redinger, *Story of Big Creek,* 136, 150.

Infrastructure: Roads and Camps

Accomplishing these engineering feats required the establishment of extensive infrastructure, made especially challenging by climate and topography. Florence Lake is free of snow only six months per year, and is separated from Huntington Lake by Kaiser Peak, which reaches over 10,000' in elevation. When the development began in early 1920, then, the main focus was road construction and the establishment of working camps, which were given the '60' series of numbers by SCE. First to be constructed was Camp 60, at the tunnel outlet near the upper end of Huntington Lake. As work on the camp continued, SCE construction forces began building a road from Huntington Lake up to Kaiser Pass (9,305'). As Redinger recounts,

> Late that summer [1920]… the road over Kaiser Pass was started by our own forces under the direct supervision of Harry M. Allen, general foreman. Men, mules, plows, scrapers, and a donkey engine, constituted the outfit. Although a preliminary survey had been made, the actual location took place as the men, mules, and scrapers pushed ahead. The wood-burning donkey engine, with its long reels of cable, pulled itself along and was used to remove boulders, trees, etc., that were too much for the mules...
>
> Following the road closely was a line crew, cutting and setting native poles for the construction of a 30,000 volt transmission line from Big Creek, since power was one of the most important items to have available.[8]

Just over the peak, Camp 61 was established at the site of the first of two tunnel adits in November 1920. Since the camps would become impassable with the onset of winter, it was a scramble not only to build the bunkhouses, warehouses, and workshops, but also to store enough supplies to feed the more than 1,000 men who would be isolated on the mountain for the next six months. SCE's construction workforce was fortunate, since snow came late in 1920, just before Christmas.[9] Meanwhile, excavation for the Ward Tunnel began. Tunnel crews began driving an adit from the tunnel outlet at Camp 60 (Huntington Lake) in October 1920, reaching tunnel grade in late July 1921. Excavation of the adit at Camp 61 began in In November 1920 and reached tunnel grade in February 1922.[10]

In the Summer of 1922 SCE crews extended the road from Camp 61 to Florence Lake. Along the way, Camp 62 was established at the site of the second tunnel adit, while Camp 63 was built at Florence Lake Dam. Camp 63 consisted of approximately 40 frame buildings located near the tunnel intake, about 1000' southwest of the spillway. Most of these structures were prefabricated 1-story frame bunkhouses used by Edison in many of its camps, plus a cook house, mess hall, and hospital. Larger working structures were located around the tunnel entrance at the west side of the camp, including a tool house,

[8] Redinger, *Story of Big Creek*, 100.
[9] Ibid., 102.
[10] Ibid., 116.

warehouse, time office, and concrete testing laboratory. A rail line connected the camp to the western end of the dam. The camp was served by a 2200 volt power line connected to the shop and warehouses, which was stepped down to 440 volts around the bunkhouses.[11]

Though sources offer little information on initial work at Camp 63, it must have focused on the intake tunnel, which was one of the six facings used to excavate the Ward Tunnel. Work on the tunnel continued year-round, with three shifts working 24 hours per day. The onset of winter isolated the camps. Communication with the outside world was established by radio-telegraph, then a new and innovative technology, which reached Camp 63 in November 1923. A team of Alaskan sled dogs with driver was recruited to carry mail, medicine, and other urgent supplies over the snowed-in Kaiser Pass.[12]

Dam Design and Preparatory Work

Florence Lake, originally a small natural lake, was named after the daughter of Mr. Starr, a local cattleman.[13] Though the general location of the dam had been chosen before 1920, the dam had not yet been designed when construction crews arrived to construct Camp 63. Field studies of the site were carried out in summer 1923, and used by architects and engineers at SCE headquarters in Los Angeles to choose an architectural concept and finalize the design. Several types of dam were considered:

> a rock-fill structure, using material from the Florence Lake Tunnel, and faced with either earth or asphalt-covered planking to make it impervious, was given extensive study… [but] test pits in nearby meadows indicated a possible shortage of material for the earth covering. Adopted finally was the multiple arch, which estimates showed to be about ten per cent lower in cost than any other type.[14]

The fact that multiple-arch dams require less concrete was an important aspect of the design's cost effectiveness, given the high cost of transporting material first to Big Creek and then to Florence Lake by road.

As work on the Ward Tunnel continued, preliminary clearing of the reservoir area began in July 1923.[15] Before construction began, however, existing water flows had to be diverted away from the dam site. Excavation for a diversion dam and diversion ditches began in April 1924. The diversion dam was constructed across the South Fork of the San Joaquin River about 600' south of the Florence Lake Dam site and had a crest at 7217', over 100' below the final level of the Florence Lake dam. The dam, a timber crib on a concrete foundation, was filled with waste rock from tunnel excavation and was 174' long, 35' high, and 62' thick at its base. The timbers were doweled to concrete piers and to each other, and both sides of the dam faced with planks coated with an asphalt

[11] Southern California Edison, "Preliminary Unit Cost Report, Florence Lake Development, as of December 31, 1927", 79; Southern California Edison Drawing A6B311.
[12] Redinger, *Story of Big Creek,* 105-110, 112.
[13] Shields, "Big Creek Dams."
[14] Redinger, *Story of Big Creek,* 134.
[15] Southern California Edison, "Unit Cost Report", 18.

compound. The dam's piers were stubbed to the concrete foundation using over 2 tons of scrap drill steel. The foundations were excavated using a Bagley scraper and aerial cableway. 173,000 board-feet of lumber were used in the diversion dam, along with 1421 cubic yards of rock fill "hauled from tunnel dump by trucks loaded by air-driven steam shovel." The diversion dam's crest was at 7217.3', over 100 feet below the final level of the Florence Lake Dam.[16]

A diversion ditch was excavated from the dam's small reservoir to the Ward Tunnel intake, allowing water diversion into the tunnel before completion of the Florence Lake Dam. Several additional ditches were excavated to allow drainage of low-lying areas of the reservoir at low water.[17]

The breakthrough of the Ward Tunnel came on February 18, 1925, almost two years ahead of schedule. Early completion of the tunnel allowed construction materials to be rapidly brought up to Camp 63 by rail for the next several weeks. On April 13, however, diversion of water into the Ward Tunnel began.[18] About the same time, Camp 65 was established at the other side of the reservoir to clear standing and fallen timber and brush over the 793 acres of the reservoir area. To cut the timber, the sawmill from Camp 61 was disassembled and relocated to Camp 65. Loggers used three 60 Best brand tractors, the first used on the Big Creek project.[19]

Dam Construction and Concrete Work

With the diversion dam complete and reservoir area being cleared, construction of the Florence Lake Dam could begin. The dam was made up of 58 arches, numbered west to east and arranged in five tangents to take advantage of the local topography. Construction facilities were established along the downstream face of the dam. A road and an electric tramway using battery-powered locomotives ran the length of the dam, allowing movement of materials by either truck or rail. To support construction, an electric shop and transformer yard were located at arch 32, and a tool sharpening shop near arch 28. At least 19 diamond drill holes were bored into the rock on both the upstream and downstream sides of the dam at a number of locations between Arches 1 and 20 as part of a testing process for dam stability.[20]

Concrete was by far the largest material by volume used at the dam; its main ingredients were aggregate, cement, and sand. To produce aggregate, trucks hauled waste rock from the tunnel dump to the rock crushing plant, located near the spillway at arches 41-42. The plant produced three grades of aggregate using No.9 and No.6 gyratory crushers. The finished product was loaded onto cars and moved to the three mixing plants via the electric tramway. All the aggregate needed for the dam was crushed, screened, and

[16] Ibid., 55-58.
[17] Ibid., 26, 62.
[18] Ibid., 14-15; Redinger, *Story of Big Creek* 130.
[19] Southern California Edison, "Unit Cost Report", 25; Redinger, *Story of Big Creek,* 138.
[20] Southern California Edison Drawing A6B311.

stockpiled in 1925, since the partial filling of the reservoir in 1926 submerged the tunnel dump area.[21]

Cement was transported to the Florence Lake site by road or tunnel and was “unsacked by Stores Department at the storage shed” near arch 32, then “transported to mixers by electric tramway.” The three mixing plants were located at arches 15, 41, and 50.[22]

Once mixed, concrete was placed by means of two Insley brand steel towers at arch 15 and in the center of the spillway. These cable-stayed towers were 300’ and 280’ tall respectively. Wet concrete was lifted up the towers by elevator and then channeled into steel chutes that could be moved to direct it to the desired location. Some concrete – notably that for the spillway – was also placed by a steam locomotive crane which operated on standard-gauge tracks on the downstream face of the dam.[23]

The curved faces of the dam made the formwork unusually complex. Forms on the intrados (underside) of the arches were built in place on 3-hinged arch trusses, while forms for the extrados (upper side of the arch) and buttresses were built from wooden panels. Rough lumber for the forms was produced by the Florence Lake sawmill (at Camp 65) from trees cut in the reservoir area, though some additional lumber also had to be transported to the site from Big Creek. A sawmill near the west end of the dam “resawed and planed” this rough lumber into sizes useful in construction.[24]

The dam was steel-reinforced throughout with steel bars and railroad rails, mostly reused from the Ward Tunnel project. The steel storage yard was located between the west end of the dam and Camp 63.[25]

Concrete work began in April 1925 and was completed to an elevation of 7291’ by November, when the onset of bad weather paused construction. Because SCE wanted to begin storing water immediately – even before completion of the dam – Camp 63 had to be dismantled and moved to a new location on higher ground. The dam reservoir reached a capacity of 35,180 acre-feet during the winter. Concrete work resumed in April 1926 and concrete work was finished on August 15 of that year. The finished dam was painted with three coats of Inertol waterproof paint. Site cleanup, backfilling, grouting, and installation of handrails, gates and other equipment continued until November 15, when Camp 64 was closed.[26]

A secondary, but significant construction project was the drilling of the vertical shaft for the tunnel intake gates, at the meeting point of the intake tunnel and the Ward tunnel. The shaft was excavated through hard rock using machine drills. Concrete in the shaft was placed by hand, using special wooden panel forms.[27]

---

[21] Southern California Edison, “Unit Cost Report”, 31; Western Construction News, “Big Creek”, 28.
[22] Southern California Edison, “Unit Cost Report”, 30, 35.
[23] Ibid., 35.
[24] Ibid., 32; Western Construction News, “Big Creek-San Joaquin Project”, 28.
[25] Southern California Edison, “Unit Cost Report”, 31; Southern California Edison Drawing A6B311.
[26] Redinger, *Story of Big Creek,* 140; Southern California Edison, “Unit Cost Report”, 9-10, 39.
[27] Southern California Edison, “Unit Cost Report”, 64.

Innovation at Florence Lake

The unusual climatic and geographical conditions of the Florence Lake Dam project led to significant innovation and experimentation by the SCE Construction Department. The emphasis on recycling and use of local materials has already been noted: all of the aggregate for dam concrete and most of the reinforcing steel were derived from tunnel construction waste, while most of the timber used for camp buildings and formwork was cut in the reservoir area and processed on the spot at Camp 65.

Concrete was an area of special innovation at Florence Lake Dam. Even in the summer, temperatures in the High Sierra often reach freezing at night. As Redinger notes, this posed problems for concrete work:

> In spite of efforts to produce concrete of the highest quality possible, it was not long after completion of the dam before the effects of freezing were recognized. The water from snow melting on the walkway would run down over the concrete in the daytime and be followed by low temperatures at night… This frost action on concrete causes it to spall – flake off – or disintegrate. It has been a most puzzling problem for years to engineers…[28]

To test the curing rates of different concrete compounds, and their resistance to freezing

> a well-equipped field laboratory was constructed. A double walled, temperature-controlled, moist air curing room was a special feature that permitted the concrete tests to be carried on unaffected by outside weather conditions.[29]

The laboratory was located on the downstream face of the dam. Tests determined that temperature fluctuations are not a major issue for concrete strength, as long as the concrete is kept from freezing, which causes the concrete to set too rapidly and reduces its tensile strength. To avoid this problem during construction, newly-poured concrete was covered with canvas to prevent it from freezing throughout the course of construction. Use of the asphaltic Inertol paint on the dam surfaces was also intended to insulate the dam and reduce spalling.[30]

The special conditions at Florence Lake led it to become part of a long-term study sponsored by the Portland Cement Association, the US Bureau of Reclamation, the State of California, and private companies. Dam concrete was regularly sampled, while new cement and waterproofing compounds were regularly tested on the structure.

Alterations and Additions

The dam retains its original appearance, though it has been subject to minor modifications and regular maintenance over the years. Most maintenance work has focused on maintenance of the concrete surface against cracking and spalling from harsh

---

[28] Redinger, *Story of Big Creek,* 142.
[29] Ibid., 135.
[30] Southern California Edison, "Unit Cost Report", 36.

weather conditions, focusing especially on the upstream surface of the dam which is constantly exposed to water. The initial material used in 1926 to waterproof and the dam's upstream surface was Inertol, a coal tar product. However, this product's dark color absorbed heat, exacerbating the problem of concrete deformation. In 1940 SCE began a new maintenance program. The first step was to identify and remove disintegrated concrete, then cover the entire surface of the arch with a 2-3 inch coat of shotcrete reinforced with wire mesh. (Shotcrete is a sprayable concrete compound, also known by the brand name Gunite). The upstream faces were then coated with Asbestile, a cement that contains asbestos, which increases its tensile strength and provides insulation. Finally, the upstream faces were painted with reflective aluminum paint to reduce heat absorption. This maintenance procedure was standard for the whole dam until at least 1990, with the exception of a few arches used to test new compounds. Asbestile was replaced with other types of polymer cement after the mid-1980s. Since 1977 mesh-reinforced shotcrete has also been used to repair 3-5 buttress heads per year.[31]

SCE experiments showed that the Asbestile cement was much more resistant to snow damage if applied as early as possible in the spring: "Asbestile applied in the Spring and subjected to water pressure during the Summer is much more resistant to snow damage during the Winter than is asbestile applied during the Fall".[32]

Despite the success of this new system, experiments with other preservation methods were made at several of the arches. Arch 13 was covered with welded steel plate between 1940 and 1960. Between 1960 and 1975 SCE used polysulfide rubber sealants on top of the shotcrete at arches 8, 13, and 53. This technique, however, did not confer any decisive preservation advantage over the shotcrete-Asbestile combination. During the drought of 1990, the dam was completely drained, allowing SCE crews to remove spalling damage on arches 53 and 54 and resurface the affected areas with gunite.[33] Though the dam has experienced an active maintenance program since its construction, none of the changes discussed here have significantly changed its appearance. Applications, moreover, are mainly on the upstream dam face, which is largely submerged in the summer.[34]

Besides repairs to the concrete, several other minor alterations have been made to the Florence Lake Dam. In 1940, the walkway along the dam crest was repaired with a linseed oil-coated shotcrete topping at the 25 westernmost and nine easternmost arches. A new reservoir minimum pool was created in 1977 at the Ward Tunnel intake to ensure continuous flow into the tunnel even at very low water levels. In 1979, a new 18" fish water pipe was installed at Arch 53.[35] Currently a 34" pipe also passes over the dam between arches 25 and 26 (View CA-167-L-13), bringing water from Hooper Diversion

---

[31] Southern California Edison, "Review of Safety at Southern California Edison Dams", 4-6.
[32] Southern California Edison, "Florence Lake Dam".
[33] Beal, "Florence Lake Dam Gets Springtime 'Makeover'", 3.
[34] Ibid.
[35] Southern California Edison, "Review of Safety", 4-5; "Facility Data, Dams and Diversions: Florence Lake Dam", 2.

into the reservoir.[36] Hooper Diversion is a small dam on Hooper Creek, constructed in 1945.[37]

Initially, the dam had a resident gate keeper in the summer months, who manually operated the intake and spillway drum gates. The intake cylinder gates were converted to automatic operation in 1999, and the original wooden intake gate house has been removed.[38] The spillway drum gates were converted to automatic operation in 2002 with the installation of electrically operated valves.[39] Both intake and spillway gates can be operated from the Big Creek control center.

Historical Context

California and the Hydroelectric Development of the West

California holds an important place in the history of hydroelectric power generation. Despite relatively low rainfall, especially in the southern regions, the high heads available in the state's mountainous terrain made waterpower important in California's industrial development. The mining industry pioneered the development of dam, flume, and penstock technologies at an early date, while Lester Pelton's development of the Pelton wheel in the 1880s dramatically increased the efficiency of the waterwheel in high head settings.[40] In California, however, this energy was typically located in remote areas far distant from urban centers, restricting its use to industries located nearby.

The development of Thomas Edison's integrated system of dynamos, lamps, and circuitry after 1880 led to a boom in urban electrification. However, widespread dependence on direct current, which had a high rate of transmission loss, made the usefulness of electricity dependent on proximity to a central station. The introduction of alternating current transmission and voltage transformers by George Westinghouse after 1886, however, opened up the possibility of transmitting electricity over long distances.[41] Much of the world's pioneering work in AC transmission took place in California, with early world records for distance and voltage set by transmission lines in Bodie (Standard Consolidated Mining Company, 1891), San Antonio to Pomona (San Antonio Light and Power, 1892), and Folsom to Sacramento (Horatio Livermore, 1895).[42]

Once the potential for connecting hydraulic and electrical power was demonstrated by Westinghouse's development at Niagara Falls (1895), hydroelectric development began in earnest, and nowhere more intensely than in California. Record-setting developments included the first 33 kilovolt (kV) transmission by Southern California Edison's Santa Ana No. 1 plant (1898); use of a 1,300' head in the Mount Whitney Power Company's

[36] Findlay Engineering, "Ninth Five-Year Safety Inspection Report, Florence Lake Dam", 9
[37] Southern California Edison Drawings 25364-O, 32551
[38] Southern California Edison, "2006 Florence Lake Dam Surveillance Monitoring Plan", 3.
[39] Duke Engineering, "Eigh Eighth Five-Year Safety Inspection, Florence Lake Dam", 5.
[40] Hay, *Hydroelectric Development in the United States, 1880-1940,* 6.
[41] Ibid., 9.
[42] Ibid., 19, 28.

plant (1899); and, superlatively, the 140-mile, 60kV Colgate transmission line built by Bay Counties Power Company in 1901.[43] "California," claimed the journal *Electrical West* in 1912, "is the birthplace of real long-distance power transmission on this continent".[44]

Southern California Edison's Big Creek project, begun in 1911, was the apex of early twentieth century hydroelectric development in California and was among the world's largest hydroelectric systems at the time of its construction. The system set successive world records for highest voltage ever used in commercial transmission (150kV in 1913, 220 kV in 1923), and used some of the highest heads in North America. In 1929, at the end of the great expansion of the Big Creek system, the five Big Creek powerhouses (1, 2, 2A, 3, and 8) each held a place among the top ten California hydroelectric plants for kilowatts and horsepower generated. Its three storage reservoirs – Florence, Shaver, and Huntington Lakes – captured runoff from 1,050 square miles, impounded 289,000 acre-feet, and were connected by almost 20 miles of hard-rock tunnel.[45]

Origins of the Big Creek System

The Big Creek system was the brainchild of visionary engineer John Eastwood (1857-1924), who first identified the Big Creek and San Joaquin River systems as an ideal location for a series of storage reservoirs and power plants. Eastwood was born in Minnesota and came to California in 1878 to work on the Pacific extension of the Minneapolis and St. Louis railroad. After establishing a private engineering firm in Fresno in 1883, Eastwood turned his attention to the Sierras. In 1893 he first visited the present location of Big Creek town, and saw its potential as the anchor point of a huge hydroelectric generating system. However, demand, distribution, and transmission networks for such quantities of power did not yet exist in California.[46]

By 1895, Eastwood had shown that high-head hydroelectric plants were feasible in the area by developing a plant further down the San Joaquin River for the San Joaquin Electrical Company (today the site of Pacific Gas & Electric Company's Wishon powerhouse). The San Joaquin Electrical Company soon went bankrupt, however, and in 1900 Eastwood turned in earnest to planning and surveying the Big Creek system, securing water rights and identifying locations for tunnels, dams, and power plants.[47] These plans, however, only came to fruition when Eastwood's engineering vision was combined with Southern California capital, in the person of Henry Huntington.

Huntington was born in 1850 in Oneonta, New York. His uncle Collis P. Huntington was the force behind the consolidation of the Southern Pacific Railroad. After the death of his uncle, and determined to make his own mark on the industry, Henry Huntington sold his

---

[43] Ibid., 30; Hughes, *Networks of Power: Electrification in Western Society, 1880-1930,* 277.
[44] Quoted in Hughes, *Networks of Power*, 265.
[45] Downing *et al.,* "Water Development on the Pacific Coast," 594-601; Federal Power Commission, *Directory of Electric Generating Plants,* 14-21; US Department of Energy, *Inventory of Power Plants in the United States,,* 41-54; *Western Construction News*, "Big Creek-San Joaquin Project".
[46] Shoup, *Hardest Working Water,* 55-59; Whitney, "John Eastwood", 38, 41.
[47] Shoup, *Hardest Working Water,* 60-62; Redinger, *Story of Big Creek,* 6.

Southern Pacific stock in 1901 and moved to Los Angeles. He became a major figure in the development of the Los Angeles region through his consolidation of street railroads, public utilities, and large real estate holdings. By acquiring land and then connecting it to the metropolis by electric railroad, Huntington was able to sell suburban parcels at hefty profits.[48]

Huntington's expanding network of street railroads depended on a reliable and inexpensive source of electrical power. In 1902, he joined with Allan C. Balch and William G. Kerckhoff to found Pacific Light and Power Company for this purpose. Kerckhoff was born in 1856 and moved to Los Angeles with his family in 1878. Through his father's lumber company he acquired an interest in the San Gabriel Valley Rapid Transit Railway, which was later absorbed by the Southern Pacific. Balch, born in New York in 1864, was trained as an electrical engineer and managed a steam-electric plant in Portland before moving to Los Angeles in 1896. Together, Balch and Kerckhoff founded the San Gabriel Electric Company, which brought them into contact with Henry Huntington.[49]

Huntington was looking for sources of electrical power, while Balch and Kerckhoff had successfully developed a hydroelectric plant on the San Gabriel River, and were proceeding with plans for another on the Kern River, 100 miles to the north. In 1901 and 1902 the three men founded Pacific Light and Power Company with the short-term aim of supplying cheap power to the street railroads, with the eventual aim of consolidating the electric utilities of the greater Los Angeles area into a monopoly.[50] Initially, 51% of the company was owned by the Los Angeles Railroad, in which Henry Huntington held a 55% interest, with the remainder owned by the Southern Pacific. Balch and Kerckhoff owned 40% of Pacific Light and Power, and appointed three of the seven directors, while Huntington named the rest. The intimate relationship between power and railroads at this early date is evidenced by the fact that the power company was formed as a subsidiary of the railroad, and not the other way around.

Kerckhoff and Balch acquired Fresno's San Joaquin Electric Light and Power in late 1902 as a large source of low cost power that could meet the projected demands of the fast-growing metropolis of Los Angeles.[51] At the time, John Eastwood was Vice President and Chief Engineer of San Joaquin Electric Light and Power. Balch and Kerckhoff were receptive to Eastwood's plans for Big Creek, and hired him in July 1902 to fully plan the system. Eastwood immediately began filing water rights claims and by late 1903 had claimed over 410,000 miner's inches of water in the basin.[52] By 1905, Eastwood had prepared plans for a system of powerhouses and transmission lines that by his estimate would offer considerable savings over similarly sized steam plants.[53] Pacific Light and Power's directors, however, were uncertain whether existing demand could

[48] Shoup, *Hardest Working Water,* 66.
[49] Ibid., 67-69.
[50] Ibid., 74.
[51] Ibid., 71.
[52] Ibid., 75.
[53] Eastwood, "Comparative Estimate of Cost of Water-Power Transmission Plant vs. Steam Plant."

absorb the huge quantities of power that Eastwood's proposed plants would generate, and decided in 1903 to prioritize steam development over hydroelectric. As a result, the period up to 1910 saw little progress on the Big Creek project.

Despite this delay, Eastwood continued to file water claims and began securing permits from the U.S. Department of the Interior to develop the hydroelectric plants, which are located on Federal land on the Sierra National Forest. Road permits were granted in 1903-1904 and comprehensive permits for the initial Big Creek development issued in 1909.[54] In 1906 Pacific Light and Power reached an agreement with Miller and Lux, a land and livestock company holding much of the downstream water rights on the San Joaquin River, and in late 1905 construction of a road from Shaver (then a timber camp) to the Big Creek basin was begun. Another route, from Auberry to Camp 1 (the site of today's Big Creek town), was begun in 1908.[55]

By 1905, Eastwood had outlined his vision for the initial development of the Big Creek system. He identified the later locations of Powerhouses 1 and 2 as the sites for two powerhouses with 2050 and 1861 feet of head, respectively. He also identified locations for Powerhouse 3 and the enlargement of larger Shaver Dam (then owned by the Fresno Flume and Lumber Company), and anticipated the use of water from Mono and Bear Creeks and Mammoth Lakes. All of these facilities were eventually constructed in the locations proposed by Eastwood – although the power eventually supplied by the system was considerably more than even he anticipated.[56]

By 1909-1910, Huntington, Kerckhoff, and Balch began seriously considering the fulfillment of Eastwood's hydroelectric plans and began to raise new capital. Pacific Light and Power Company was recapitalized in late 1909 with the help of eastern bankers and sold new bonds to raise money for the Big Creek project. At the same time, Huntington eliminated the Southern Pacific Company from the project by trading one of his interurban electric lines in Los Angeles for the Southern Pacific's 45 percent stake in the Los Angeles Railroad, Pacific Light and Power's holding company. In 1910, Balch exercised his option to buy the plans, water rights, and permits for Big Creek, all of which were held in Eastwood's name. Eastwood received 10 percent of the stock of the new Pacific Light and Power Corporation.[57] Huntington, however, used special assessments on shareholders to force Eastwood to sell his stock cheaply, depriving him of his hoped-for wealth. Despite his visionary role in designing the Big Creek project, Eastwood was excluded from involvement in its construction and ultimately received no financial reward for his work. Balch and Kerckhoff also sold their interests to Huntington about this time, leaving him with full control of the company. About the same time, in October-November 1911, Huntington secured financial backing from a syndicate of New York bankers that allowed construction to proceed.[58]

---

[54] Shoup, *Hardest Working Water,* 82.
[55] Shoup, *Hardest Working Water,* 83.
[56] Eastwood, "Comparative Estimate".
[57] Ibid., 85.
[58] Ibid., 85, 92.

Initial Construction, 1910-1913

Once the financial resources to construct the project had been secured, construction was ready to begin. Pacific Light and Power, hired the Boston-based Stone and Webster Construction Company to design and manage the construction. The contract with Stone and Webster covered the construction of the 56-mile San Joaquin and Eastern Railroad, three dams to create Huntington Lake, Powerhouses 1 and 2, the 240-mile transmission line to Los Angeles, and the necessary forebays, tunnels, and penstocks.[59]

The development as executed generally followed Eastwood's plans, although Stone and Webster's engineers favored different architectural and engineering solutions: their engineers built Cyclopean masonry dams with gravity sections rather than his proposed earth dams, and combined the generation and transmission facilities in a single structure rather than separating them in detached buildings as Eastwood had proposed.[60]

Blasting for the dam sites and tunnels began in Spring 1912. Over the following summer, 3,500 men were at work in 12 camps scattered across the construction area. At the end of 1912 excavation for the foundations of Powerhouse 1 were well underway.[61] A bitter strike in on January 1913 led to construction delays, with Powerhouses 1 and 2 completed two months behind schedule in November and December, 1913.[62]

When the initial phase of Big Creek was complete, the two powerhouses had four generating units producing 80,000 horsepower and using some of the highest heads in the country. At 240 miles long, the power lines connecting Big Creek with Los Angeles were among the world's longest, and set a new record for using 150kV in commercial transmission. The difficult mountain terrain, high heads, and huge turbines gave the Big Creek plant an essentially experimental character. *Electrical World* recognized the feats achieved in the initial construction of the system as "one of the most advanced contributions of the engineer to the welfare of civilization".[63]

Intermission, 1914-1919

The onset of the European war in late 1914 affected both the American credit markets and power consumption. It became difficult for companies such as Pacific Light and Power to raise money for capital projects, while electrical demand in Los Angeles was not growing fast enough to require immediate construction of additional power plants or generating units.[64] Some tunnel and dam work continued at Big Creek, including raising the three dams at Huntington Lake in summer 1917 to increase its storage capacity.[65]

---

[59] Redinger, *Story of Big Creek,* 11.
[60] Eastwood, "Progress Report for 1903-1904 of Right of Way Surveys and Outline Plan for Power Plant No. 1."
[61] Stone and Webster, "Progress of the Big Creek Initial Development: Report to Pacific Light and Power Corporation, January 1, 1913," 3.
[62] Stone and Webster, "Progress 1913", 3.
[63] *Electrical World,* "The 150,000-Volt Big Creek Development – I," 33.
[64] Shoup, *Hardest Working Water,* 153.
[65] Redinger, "Progress on the Big Creek Hydro-Electric Project, Part I", 722.

More significant for the future development of the Big Creek system was the 1917 merger between Pacific Light and Power and Southern California Edison (SCE). The merger combined the extensive street railroad interests of PLP – and excess electric generation capacity – with Edison's rapidly expanding residential electricity business.

The economic boom after the end of the World War I led to rapid urban and industrial growth in Los Angeles that rapidly increased electrical demand. As a result, the previously modest expansion plans for Big Creek were accelerated, beginning a construction boom that lasted until 1929.[66]

The Great Expansion: Electrical Plants

In January 1921 the California Railroad Commission approved expansion of Powerhouse 1 and construction of Powerhouse 3 and Powerhouse 8.[67] Big Creek town soon saw the addition of thousands of new construction workers. Powerhouse 8 was built between January and August 1921.[68] A pioneer facility in several respects, it was the first commercial powerhouse ever designed for 220kV transmission and set records for construction speed, which earned the plant the monicker of the 'Ninety-day wonder'.[69] Soon after the completion of Powerhouse 8, construction began on the tunnels, forebays, and penstocks for Powerhouse 3. The three initial units of "the electrical giant of the West", were placed online on September 30, October 2, and October 5, 1923.[70] The three units of Big Creek No. 3 made up the largest hydroelectric plant in the west at the time of their construction, with an aggregate capacity of 75,000 kW. At the same time, existing plants were expanded: third and fourth generating units were added to Big Creek Nos. 1 and 2 between 1921 and 1925.[71]

After the construction of Florence Lake and Shaver Lake, two additional generating units were built next to Powerhouse 2. Powerhouse 2A's generators were among the largest in the world at the time of their installation and harnessed a 2,418' head, the highest in the Big Creek system.[72] When the second unit of Powerhouse 8 went on line in June 1929, fifteen generating units were in service, with an aggregate capacity of 344,500kW. The system went from generating 213 million kilowatt-hours in 1914 (its first full year of service) to 1.6 billion in 1928.[73]

The Great Expansion: Dams and Tunnels

All of this generation, however, was dependent on the infrastructure that brought water to the powerhouse turbines. Southern California has a semi-arid climate with seasonal winter rainfall, making water storage a necessity in the summers to ensure a predictable

[66] Shoup, *Hardest Working Water,* 162.
[67] Untitled memorandum, Folder 6, Box 302, Southern California Edison Collection, Huntington Library, San Marino, CA.
[68] *Journal of Electricity and Western Industry,* "Big Creek No. 8 Hydro-Electric Unit Completed," 160.
[69] Shoup, *Hardest Working Water,* 190; *Electrical World,* "First 220,000-Volt Station Completed," 117.
[70] Redinger, "Progress on the Big Creek Hydro-Electric Project, Part V," 991.
[71] *Journal of Electricity,* "Big Creek No. 2 Power House Being Extended 56 ft," 297.
[72] *Electrical West,* "Southern California Edison's Advance," 829.
[73] Southern California Edison, *Annual Report 1928*, 21.

supply of water to the powerhouse turbines. Storage reservoirs and tunnels were thus the most crucial parts of the system, and as such absorbed most of Southern California Edison's investment at Big Creek.

In 1917 Southern California Edison purchased Shaver Lake, originally built by the Fresno Flume and Lumber Company as part of their logging and sawmill operation. The Shaver Tunnel, which connected Shaver Lake to Powerhouse 2, was begun in February 1920 and completed in May 1921.

The lynchpin of the great expansion was the Florence Lake development, which included the construction of Florence Lake Dam high up on the South Fork of the San Joaquin River at 7327' elevation and a hard rock tunnel 13 miles long connecting it to Huntington Lake. The tunnel, later named the Ward Tunnel after SCE President George C. Ward, was the longest water tunnel in the world. Beginning in 1920, thousands of workmen labored around the clock at six working faces to cut through solid granite, finishing the tunnel in April 1925. Florence Lake Dam was constructed in 1925-1926 and was the longest multiple-arch dam in the world at the time of its construction.[74]

As soon as Florence Lake was completed the Edison construction force moved to Mono and Bear Creeks, tributaries of the South Fork San Joaquin River. Two small diversion dams directed water through tunnels and aboveground piping into a steel siphon three miles long that delivered water into the Ward Tunnel. Construction began in Spring 1926 and began delivering water in November 1927.[75]

Powerhouse	**Units**	**Capacity (kW)**
1	4	66,000
2	4	56,000
8	2	56,400
3	3	75,000
2A	2	93,000
Total	**15**	**344,800**
Reservoir		**Capacity (acre-ft)**
Shaver		135,283
Huntington		89,166
Florence		64,406
Total		**288,855**

Table 1. Electrical and Storage Capacity in the Big Creek System, 1929

[74] Redinger, *Story of Big Creek,* 136, 150.
[75] Redinger, *Story of Big Creek,* 149; Shoup, *Hardest Working Water,* 136.

Simultaneous with the Mono-Bear Diversion was the expansion of Shaver Lake to form the largest reservoir in the Big Creek system. The new Shaver Lake Dam, begun in April 1926 and completed in October 1927, was the longest and largest gravity dam in California, forming a reservoir of 2,200 acres with a capacity of more than 135,000 acre-feet. The new Shaver Lake stored excess water from Florence and Huntington Lakes and also made possible the new high-head generating units at Powerhouse 2A.[76]

At the end of the great expansion, the number of electric generating units in the Big Creek system had grown from four to 15 and generating capacity from 56 to 345 megawatts. Construction of its complex system of dams and tunnels set records for speed, size, and technical innovation; when finished, this expansion of the system gave SCE control of almost all of the flow over the 1,050 square mile watershed of the upper San Joaquin River, adding an industrial function to a wilderness landscape and providing the initial infrastructure for tourism on the western slope of the high Sierra.[77]

The Great Expansion: Life in Big Creek's Construction Camps

In 1920, the town of Big Creek (then called Cascada), had only 525 inhabitants, overwhelmingly males of European descent[78] Five years later, however, the population of the area had grown by over 5,000, making Big Creek a boom town. By 1925,

> the main street of Big Creek was crowded with places of business, including a hardware store, butcher shop, bakery, laundry, dry goods shop, art shop, three barber shops, real estate office, movie theatre, restaurant, six dentists' offices, two garages, a general merchandise shop, beauty shop, and women's apparel store. Every two weeks, three Fresno banks sent representatives to cash checks and receive deposits.[79]

Though Big Creek town was booming, during the great expansion most of SCE's 5000 workers in the area lived in remote camps in the surrounding mountains, near their work sites. The camps above the snow line, such as those for the Ward Tunnel, Florence Lake Dam, and Mono-Bear Diversion, consisted of portable-frame bunkhouses that could be shipped in sections and moved as needed. A 'radical' innovation came in 1923, when SCE began to offer bedding to its construction teams – previously, men had furnished their own.[80]

Besides bunkhouses, a typical camp included a dining hall, cook house, warehouse, machine shop for tool repairs, cold storage facility for food, and sometimes garages, hospitals, and recreation halls. Given their remote locations and the high cost of transporting materials, camps had to be mostly self-sufficient and devoted much effort to creative recycling of waste materials.[81] Transporting food alone was a monumental effort, given that 450,000 meals were served to Big Creek workers each month. Though

---

[76] Ibid., 153.
[77] Redinger, *Story of Big Creek,* 150; Shoup, *Hardest Working Water,* 156.
[78] Fourteenth Census of the United States, Cascada Precinct, Fresno County, California.
[79] Fresno Bee, "Pupils Will Play Where Big Creek Landmark Stood."
[80] Redinger, *Story of Big Creek,* 90.
[81] Shoup *Hardest Working Water,* 155; Redinger, *Story of Big Creek,* 101.

employees paid for food, Edison subsidized commissary and cookhouse costs throughout the period of construction, averaging them into overall construction costs.[82]

Life in the camps was isolated, doubly so for those workers who remained through the winters of 1920-1925 during construction of the Ward Tunnel. With snow 10 feet deep or more blocking Kaiser Pass, a team of Alaskan sled dogs led by one Jerry Dwyer were brought in to transport mail, medicine, and other light supplies. The challenges of weather and terrain also led to the construction of a radio and telephone network enabling instantaneous communication between Big Creek and the outlying camps.[83]

SCE also took measures to enliven the isolation of camp life and build community. A mobile cinema was established:

> Once, and sometimes twice, a week in each of these camps the company provides a free motion picture performance for the workmen. A portable projector and a light automobile made the tours of these camps on regular schedules and gave the men an exhibition almost identical with those seen in motion picture houses in the cities and towns. It consisted of a news reel, a comedy, and a drama… once… the cinematographers' outfit and films were conveyed 30 miles over mountain tops on a big sled drawn by a team of Alaskan sled dogs over a road drifted 20 feet deep with snow and impassable for horses.[84]

SCE organized other entertainments in camp, such as dances, boxing matches and baseball games. Many camps also had a library. Many workers enjoyed fishing in the mountain streams, and Redinger also notes that gambling was common in the camps, as was home-brewing (despite ongoing Prohibition).[85]

Despite these efforts, retention of skilled employees was an ongoing problem. SCE experienced very high employee turnover at Big Creek, especially in the construction workforce. As the shareholder magazine *Edison Partners* magazine reported in 1923:

> Under the plan of permanent organization of the construction forces the labor turnover on the Big Creek-San Joaquin project has been constantly decreasing, until the average for the past year was forty per cent, and the lowest average for any month twenty-six percent. Good living conditions, excellent food, commissary stores which sell everything from clothing to cigarettes at the same prices that obtain in the large cities, amusements, recreation halls, and greatest of all, that intangible thing which can perhaps be termed "camaraderie" and co-operation tend to contentment

[82] In the unit cost developments and price books for the Big Creek plants, these losses are included in the cost of materials and labor, suggesting that the company saw these subsidies as a routine construction expense.
[83] Redinger, *Story of Big Creek,* 111-113, 155-157.
[84] Lyons, "Camera's Part in Record Industrial Project," 10
[85] Redinger, *Story of Big Creek,* 102.

> among the men, and a desire to consider the project in the nature of a life work.[86]

Despite the rosy prose, the writer concedes an average of *40 percent* turnover in the construction workforce, suggesting that many of the workers on the construction jobs at Big Creek during this time found the work too hard, the conditions too isolated, or the pay too low to remain on the job for more than a few months.

Big Creek in Context

Between late 1911, when construction began on Big Creek Powerhouse 1, and 1929, when Powerhouse 2A was completed, the Big Creek region was transformed from inaccessible wilderness to an industrial landscape and company town intimately connected to the economy of greater Los Angeles. Each phase of the great expansion was marked by pioneering technical achievements in transportation, dam building, tunnel driving, powerhouse design, and transmission line construction. In the process, a community developed that was marked by a combination of pioneer spirit and corporate paternalism. For many who worked in Big Creek, such as David Redinger, the experience was one that defined their lives.

---

[86] *Edison Partners,* "Contented Labor," 6.

Structural Design

Description

Florence Lake Dam is a reinforced concrete multiple-arch dam 3156’ long and 149’ high at its maximum point. Its crest is at 7239’ elevation. It is composed of 58 arches in five tangent sections that follow the underlying bedrock of glacially scoured granodiorite. The tangents are connected at three points by angle buttresses and at the fourth point by the dam’s spillway, while an abutment anchors each end of the dam.[87] View CA-167-L-1 shows the downstream face while views CA-167-L-20 through CA-167-L-22 present a panorama of the upstream face. Views CA-167-L-18 and CA-167-L-19 show the western abutment of the dam.

Each of the dam’s arches has a 50’ span and a curvature of 180˚. The arches incline 48˚ from vertical. The uppermost 34’ of the arches are 18” thick, expanding to approximately 4.5’ thick at their lowest points. Fifty-three ‘normal’ buttresses connect the arches in the linear sections. These are 2’-3” thick in the top 54’ of the dam, increasing to 7’-6” thick at their lowest elevation. Views CA-167-L-2 through CA-167-L-6, CA-167-L-11 and CA-167-L-12, and CA-167-L-14 through CA-167-L-17 present various arches and arch butttresses from their downstream sides. Elevation, plan, and section drawings of a ‘typical’ arch are shown on View CA-167-L-27.

The three angle buttresses, which join tangents of the dam, are gravity block sections with a minimum thickness of 2’-3” at their crests. View CA-167-L-23 shows one of these angle buttresses from the upstream side of the dam between Arches 9 and 10. The spillway, which also connects two tangents, is a gravity block section 113’ wide. The upstream face of the dam is covered with reflective paint to minimize expansion from heat absorption.[88] View CA-167-L-7 shows the spillway and natural rockface below. A walkway 3’ wide with galvanized pipe hand railings runs along the entire length of the dam and is visible in View CA-167-L-18. Access to the walkway is provided by concrete staircases on the upstream faces of angle buttresses 25 and 49, and by steel staircases on the upstream faces of buttresses 32 and 28. There are also steel ladders on the north and south spillway piers (CA-167-L-8).[89]

The dam sits on the South Fork of the San Joaquin River and impounds runoff from a drainage area totaling 171 square miles and extending to over 14,000 feet in elevation. The resulting Florence Lake reservoir has a capacity of 64,406 acre-feet and covers 962 acres when full. The primary purpose of the dam is to supply water for power generation. Water flows from the reservoir through the Ward Tunnel into Huntington Lake, whence it is distributed to the powerhouses of the Big Creek System. Florence Lake also provides recreational services to users of Sierra National Forest.

---

[87] Southern California Edison, “Florence Lake Dam”, “Review of Safety”, 1, “Unit Cost Report”, 9; Western Construction News, “Big Creek”, 28,
[88] Southern California Edison, “Florence Lake Dam”, “Unit Cost Report”, 9.
[89] Southern California Edison, “Unit Cost Report”, 9.

Mechanicals and Operation

The mechanical elements of the dam consist of five devices for releasing water from the reservoir. Four of the devices – the spillway, sluice gates, Stoney gate, and fish water outlets – are used to regulate the height of the reservoir water. The fifth device – the intake tunnel – supplies water for hydroelectric plants downstream via the Ward Tunnel.

Spillway

Spillways allow controlled release of water from a reservoir. They are also used to drain excess water from a dam to prevent overtopping that can damage or destroy the structure. The Florence Lake Dam spillway is a reinforced concrete gravity block section located between arches 36 and 37 and composed of two floating drum gates, each 51' long and forming a rough triangle 13' on a side when viewed in section. The gates are hinged on the upstream side. When lowered, each gate rests in a concrete chamber called the 'drum pit'. To raise the gates, the drum pit can be filled with water. The gates have a 12' effective height, which allows the overall reservoir levels to be set between 7315.5' and 7327.5'. Drum gates were chosen for the dam "because of the ease in handling trash and drift".[90] View CA-167-L-24 shows the upstream face of the spillway, CA-167-L-7 the downstream face, and CA-167-L-9 the spillway surface. Plan, section, and elevation drawings of the spillway are shown in View CA-167-L-28.

The drum gates were purchased from Llewellyn Iron Works and their hinge castings were purchased from Baker Iron Works, both of Los Angeles. Water levels in the drum pits are controlled by automatic float-operated cylinder valves, operated by a lever connecting to the drum gate hinge pin. These valves were purchased from the Joshua Hendy Iron Works of Sunnyvale, CA.[91]

If water levels exceed 7327.5', excess flow passes over a weir and opens the cylinder valves, draining the drum pit, lowering the spillway gates, and thus allowing excess water to flow out of the reservoir. The weir and drum pit intakes are equipped with steel racks to prevent debris from entering.[92] The drum gates in their lowered position are visible in View CA-167-L-10.

Sluice gates

A sluice gate is a plate that can be raised to allow water to pass beneath it. The Florence Lake Dam's two sluice gates run parallel to the bed of the South Fork San Joaquin River on either side of arch 53. Located at 7205' elevation, near the base of the dam, they allow the reservoir to be drained from the bottom as well as the top. The gates themselves measure 46" x 46" and are raised and lowered by separate hydraulic jacks located on the top of the dam. When raised, the gates allow water to pass through a steel transition section and then into 36" diameter cast iron pipes that extend through the dam. The gates are protected on their upstream side by trash racks that prevent debris from entering. The

[90] Western Construction News, "Big Creek", 30.
[91] Southern California Edison, "Unit Cost Report", 51.
[92] Southern California Edison, "Florence Lake Dam", "Unit Cost Report", 12.

gates, cast iron pipes, and transition sections were purchased from Llewellyn Iron Works of Los Angeles.[93]

Oil for the hydraulic jacks is supplied by a 50-gallon oil tank and a single pump located on arch 53. The pump was powered by a 4 horsepower Redwing gasoline engine, model 6166-K. A Ford gasoline tank held fuel for the engine and a salvaged water tank provided cooling water. The pump and engine were installed in a housing of 14-gauge steel on the walkway between arches 52 and 53.[94]

Stoney Gate

A Stoney gate (named for Irish engineer Bindon Stoney) is a type of water control gate that can be raised vertically on rollers to allow water to pass underneath. In the Florence Lake Dam, the Stoney gate is located between the two sluice gates at the bottom center of arch 53. Made of massive structural and plate steel measuring 10’x24’ and weighing 22 tons, the gate is only used for emptying the reservoir completely at very low water levels. It is opened by applying heavy traction to a system of steel cable rigging. The gate was constructed in the Big Creek shops.[95]

Fish Water Outlets

The dam also includes two fish water outlets in order to supply sufficient water to maintain fish stocks on the South Fork San Joaquin River downstream. The outlets are two 8” pipes with 8” sluice gates that run parallel to the natural course of the river. The first pipe is 42’ long and passes through the bottom of arch 53 at 7195’ elevation. A ball bearing handwheel on the walkway atop the dam operates its sluice gate via a stem connection. The second pipe passes through arch 51 at 7250’ elevation and measures 52’ in length. Its sluice gate is on the downstream side of the arch and is hand operated. Each pipe is equipped with steel trash racks at their intake openings.[96]

Intake

While the other mechanical elements of the dam are designed to control reservoir water levels, the intake tunnel supplies water for hydroelectric generation via the Ward Tunnel. As originally constructed, the intake had three main parts: the intake tunnel, the gate shaft, and the gate house. (The original gate house has since been disassembled and replaced with automatic operation). Elevation and plan drawings of the intake apparatus are visible in View CA-167-L-29.

The intake tunnel was excavated horizontally 318’ through bedrock to connect to the end of the Ward Tunnel. The intake tunnel portal, located underwater inside the reservoir at 7219’ elevation, is covered with a trash rack made of heavy structural steel bars 3/8” x 5”.

[93] Southern California Edison, “Unit Cost Report”, 11, 43.
[94] Ibid., 45.
[95] Ibid., 12. 48.
[96] Ibid., 12, 49.

The rack structure measures 16’ x 45’ x 30’ high and is sealed into concrete around the tunnel portal. Forty-nine tons of steel were used in its construction.[97]

Inside the intake tunnel is a Venturi tube used to measure the volume of water passing through the tunnel. Venturi tubes are lengths of pipe that are narrower in the middle than at the ends. The constriction in the middle of the tube increases the velocity of water while decreasing water pressure. The differential between the initial water pressure and the pressure in the constricted section can be used to calculate the volume of water flow through the tube. Pressure measurements are made by a Venturi meter, which draws water from the points of maximum and minimum pressure via small tubes and connects them at their ends to allow a reading of the differential pressure head. The Venturi tube in the Florence Lake Tunnel intake is 157.5” x 99” in section and 48’-6⅝/” long, and weighed 31 tons. It is made up of a bronze-lined cast iron throat casting in the middle and riveted plate steel at the ends. Its centerpoint is 224’ from the tunnel portal and 94’ from the cylinder gates. The throat casting was purchased from Builder’s Iron Works of Providence, RI and the plate steel from Lacy Manufacturing Company of Los Angeles.[98]

The intake gates regulate water flow between the Florence Lake Dam and the Ward Tunnel. The gate shaft is sunk vertically 144’3” through bedrock and is 14’ x 29’ in section. The bottom of the gate shaft connects to the end of the Ward Tunnel 21’ below the level of the intake tunnel. The gates themselves are two riveted steel cylinders, 6’-¾” in diameter and 110’-10” long, which move in a concrete housing. When open, the gates float on water from the intake tunnel, which pushes upward into the gate shaft and floats the steel cylinders. To close the gates, hydraulic jacks in the gate house force the gates downward, overcoming water pressure in the intake tunnel and closing the connection between the Florence Lake reservoir and the Ward Tunnel. View CA-167-L-29 shows these gates in their down, or closed, position. Besides the gates themselves, the shafts contain piping for ventilation and the Venturi meter, as well as steel ladders allowing maintenance access to the tunnels. The gate cylinders were purchased from Western Pipe and Steel and the hoisting mechanism from Llewellyn Iron Works, both of Los Angeles.[99]

When the dam was built, the gate house sat atop the two shafts at 7432’ elevation, on dry land above surface of reservoir. The gate house was of wood construction with Fenestra brand steel sash, sugar pine panel doors, and roof covered in waterproof Petrolastic brand asphalt. The floor of the structure was made of Two I-beam girders that supported the steel floor plates and the two hydraulic jacks, each of which was positioned on top of one of the cylinders. The jacks were actuated by Quimby No. 2½ high pressure oil pumps, which were powered by 18 horsepower, 4-cylinder Novo Model AF gasoline engines. Oil was supplied from a 112-gallon oil sump tank. The gate house also contained several recording instruments. A Type M Venturi Register was connected to three Stevens Type

---

[97] Ibid., 65.
[98] Ibid., 74.
[99] Ibid., 71.

A recorders “connected through differential gears” to the Type M register. Two more Stevens Type A Recorders recorded water levels in the tunnel and the reservoir, respectively. The Type M recorder was purchased from Providence, RI and the Type A recorders from Los Angeles.[100]

Site Information

The Florence Lake Dam is located in a high alpine landscape characterized by a mix of coniferous forest and glacially-scrubbed granite exposures. The site is reached by the Florence Lake Road, constructed by SCE in 1921-1925 but surrendered to the US Forest Service in 1929.[101] The road stretches 21 miles from the Ward Tunnel outlet at Huntington Lake to the Florence Lake Gate House. Today, a parking lot is located near the west side of the dam. Besides its hydroelectric uses, the Florence Lake area has mainly recreational use by summer visitors.

Sources of Information

Research Sites

Archival research for this report was conducted in the following locations:

- Water Resources Library, University of California, Berkeley, California
- Bancroft Library, University of California, Berkeley, California
- Engineering Library, University of California, Berkeley, California
- University of California Northern Regional Library Facility, Richmond Field Station, Richmond, California
- Southern California Edison Collection, Huntington Library, San Marino, California
- Plant Accounting Department, Southern California Edison Company, Rosemead, California
- Northern Hydro Division Headquarters, Southern California Edison Company, Big Creek, California

Primary Sources

Duke Engineering and Services. “Eighth Five-Year Safety Inspection, Florence Lake Dam.” April 2002. History and Information File, Northern Hydro Division Headquarters, Big Creek, California.

Eastwood, John S. “Progress Report for 1903-1904 of Right of Way Surveys and Outline Plan for Power Plant No. 1,” 1904. Folder 11, Box 302, Southern California Edison Papers, Huntington Library, San Marino, California.

[100] Ibid., 72-75.
[101] Redinger, *Story of Big Creek,* 151.

——. "Comparative Estimate of Cost of Water-Power Transmission Plant vs. Steam Plant, for W.G. Kerckhoff, President, Pacific Light and Power Company," 1905. Document No. 12871, History and Information File, Northern Hydro Division Headquarters Library, Big Creek, California.

Findlay Engineering and GEI Consultants. "Ninth Five-Year Safety Inspection Report, Florence Lake Dam." December, 2006. History and Information File, Northern Hydro Division Headquarters, Big Creek, California.

Fourteenth Census of the United States, Cascada Precinct, Fresno County, California, 1920. On file, University of California at Berkeley.

Shields, Jane Ann. "Big Creek Dams." Typescript, 1988. History and Information File, Northern Hydro Division Headquarters, Big Creek, California.

Shoup, Laurence H. "*The Hardest Working Water in the World": A History and Significance Evaluation of the Big Creek Hydroelectric System.* Southern California Edison Company, Rosemead, California, 1987.

——. *Life at Big Creek Town 1929-1947: Historic Context Statement and National Register of Historic Places Significance Evaluation.* Southern California Edison Company, Rosemead, California, 1997.

Southern California Edison. *1927 Annual Report, Big Creek Division.* History and Information File, Northern Hydro Division Headquarters, Big Creek, California.

——. "Preliminary Unit Cost Report, Florence Lake Development, as of December 31, 1927." On file, Southern California Edison Company, Rosemead, California.

——. *1928 Annual Report, Big Creek Division.* History and Information File, Northern Hydro Division Headquarters, Big Creek, California.

——. "Facility Data, Dams and Diversions: Florence Lake Dam." Undated memorandum (1980s). History and Information File, Northern Hydro Division Headquarters, Big Creek, California.

——. "Florence Lake Dam." Undated memorandum (1980s). History and Information File, Northern Hydro Division Headquarters, Big Creek, California.

——. "Review of Safety at Southern California Edison Dams." Memorandum, April 1992. History and Information File, Northern Hydro Division Headquarters, Big Creek, California.

——. "2006 Florence Lake Dam Surveillance Monitoring Plan." May 1, 2007. History and Information File, Northern Hydro Division Headquarters, Big Creek, California.

——. Drawing A6B311, 1924. On file, Southern California Edison Company, Rosemead, California.

——. Drawing 25364-O, 1945. On file, Southern California Edison Company, Rosemead, California.

——. Drawing 32551, 1945. On file, Southern California Edison Company, Rosemead, California.

Stone and Webster Construction Company. “Progress of the Big Creek Initial Development: Report to Pacific Light and Power Corporation, January 1, 1913.” Water Resources Library, University of California, Berkeley.

Secondary Sources

Beal, Charles. “Florence Lake Dam Gets Springtime ‘Makeover’”. *Edison News,* October 26, 1990.

Bradley, Betsy Hunter. *The Works: The Industrial Architecture of the United States.* New York: Oxford University Press, 1999.

Downing, P.M., O.B. Caldwell, E.R. Davis, W.G.B. Euler, and C.C. MacCalla. “Report of the Sub-committee on Water Development on the Pacific Coast.” In National Electric Light Association, *Papers Reports and Discussions, Hydro-Electric and Transmission Sections Technical Sessions, National Electric Light Association Thirty-Eight Convention,* 510-601. San Francisco: National Electric Light Association, 1915.

Electrical West. “Southern California Edison’s Advance.” April 21, 1928, 829.

Electrical World. “The 150,000-Volt Big Creek Development – I.” January 3, 1914, 33-38.

——. “The 150,000-Volt Big Creek Development – II.” January 10, 1914, 85-88.

——. “Transmission at 220,000 Volts a Fact.” May 12, 1923, 1107.

Federal Power Commission. *Directory of Electric Generating Plants.* Washington, D.C.: Federal Power Commission, 1941.

Fresno Bee. “Pupils Will Play Where Big Creek Landmark Stood.” February 27, 1912, p. 12a.

Hay, Duncan. *Hydroelectric Development in the United States, 1880-1940.* Washington, D.C.: Edison Electric Institute, 1991.

Hughes, Thomas P. *Networks of Power: Electrification in Western Society, 1880-1930.* Baltimore: Johns Hopkins University Press, 1983.

Journal of Electricity. “Big Creek No. 2 Power House Being Extended 56 ft.” 54 (1925): 212.

Journal of Electricity and Western Industry. “Big Creek No. 8 Hydro-Electric Unit Completed.” August 15, 1921, 160.

Lyons, Lurline. “Camera’s Part in Record Industrial Project.” *American Cinematographer,* June 25, 1925, pp. 9-10.

Redinger, David. *The Story of Big Creek.* Los Angeles, CA: Angelus Press, 1949.

——. "Progress on the Big Creek Hydro-Electric Project, Part I". Compressed Air Magazine, December 1923, 720-724.

——. "Progress on the Big Creek Hydro-Electric Project, Part V". Compressed Air Magazine, September 1924, 989-992.

U.S. Department of Energy. *Inventory of Power Plants in the United States, 1981 Annual.* Washington. D.C.: U.S. Department of Energy, 1982.

Western Construction News. "Big Creek-San Joaquin Hydro-Electric Project of the Southern California Edison Company." July 10, 1927, 28-36.

Whitney, Charles A. "John Eastwood: Unsung Genius of the Drawing Board." *Montana: The Magazine of Western History,* Summer 1969, 38-48.

Likely Sources Not Yet Investigated

The author is not aware of sources not yet investigated.